MIMO Adaptive Control with ϵ-Modification and On-line Singularity Avoidance Method for Hyper-Redundant Robotic Arm

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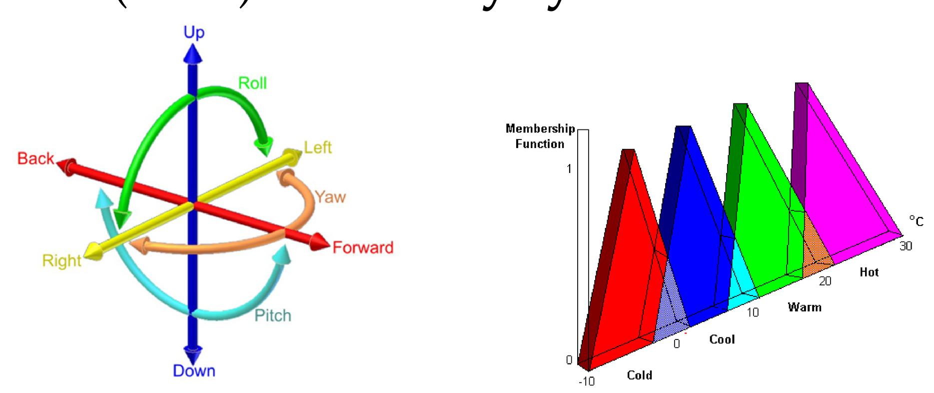
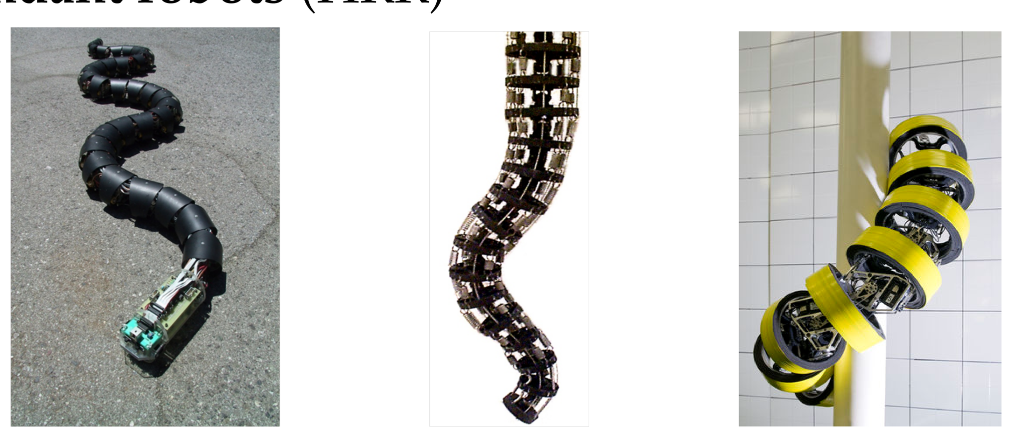
Introduction

- **Degree of freedom** (DOF) and **Fuzzy system**



(a) Degree of freedom (b) Fuzzy system

- **Hyper-redundant robots** (HRR)

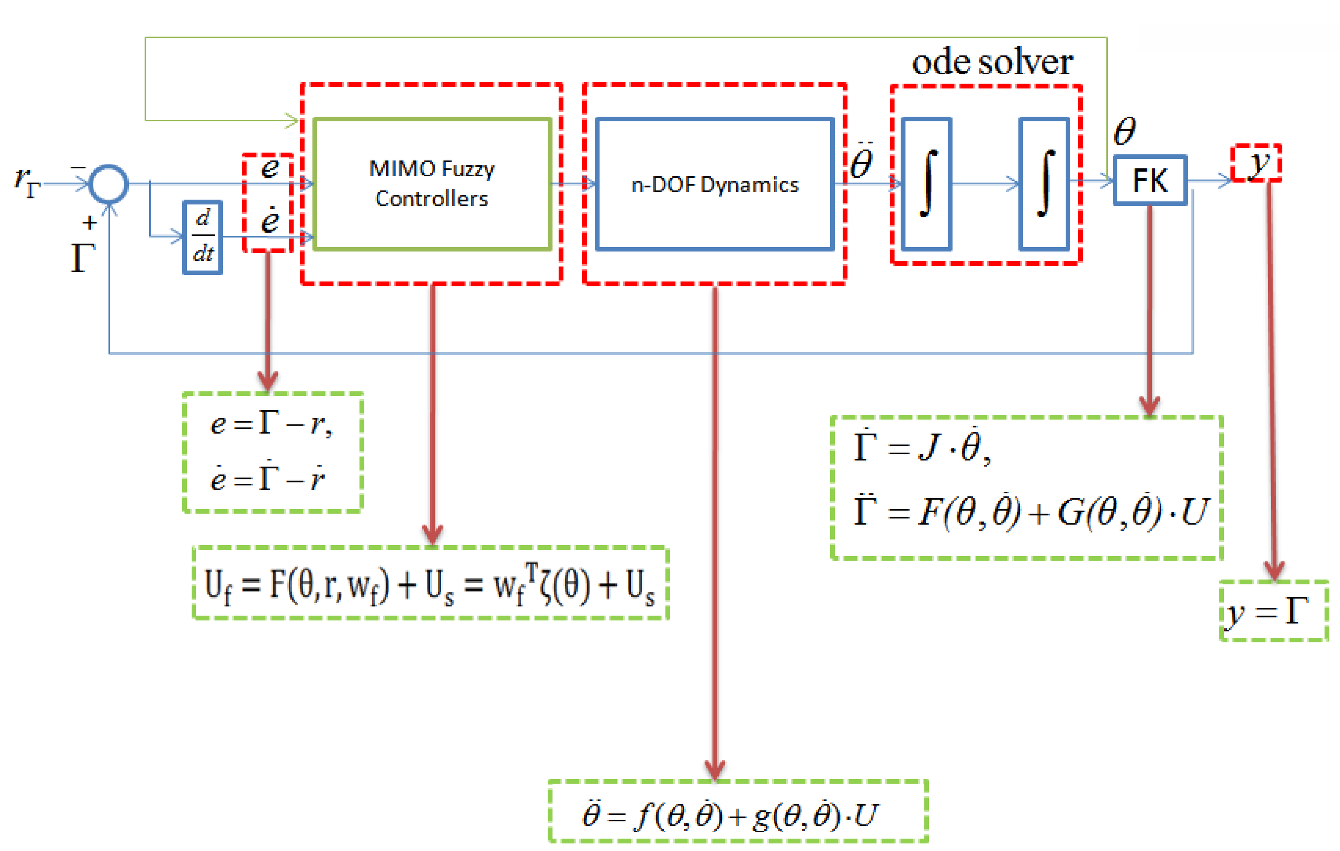


(a) Snake (b) Elephant trunk (c) Tentacle

Objective

- Design a MIMO adaptive controller that uses a fuzzy system with ϵ-modification for a 9-DOF HRR.
- Apply an on-line task modification method (OTMM) to achieve singularity avoidance for HRR at the velocity level.

MIMO Adaptive Control in Workspace



Error Boundaries with ϵ-modification

We represent each ideal controller as

$$\tau^* = \mathcal{F}(x,r,\theta^*) + W_u = \theta^{*T}\zeta(x,r) + W_u.$$

The fuzzy system approximation of τ^* is given by

$$\hat{\tau} = \mathcal{F}(x,r,\hat{\theta}) + U_s = \hat{\theta}^T\zeta(x,r) + U_s,$$

where $U_s = -(W_u + B|e|/2g_0^2)\mathrm{sat}(e/\varepsilon)$ is a stabilizing control term.

In the practical case, we replace the sliding mode stabilizing control term with $U_s = -(\hat{W}_u + \hat{B}|e|/2g_0^2)\mathrm{sat}(e/\varepsilon)$, and the adaptation laws

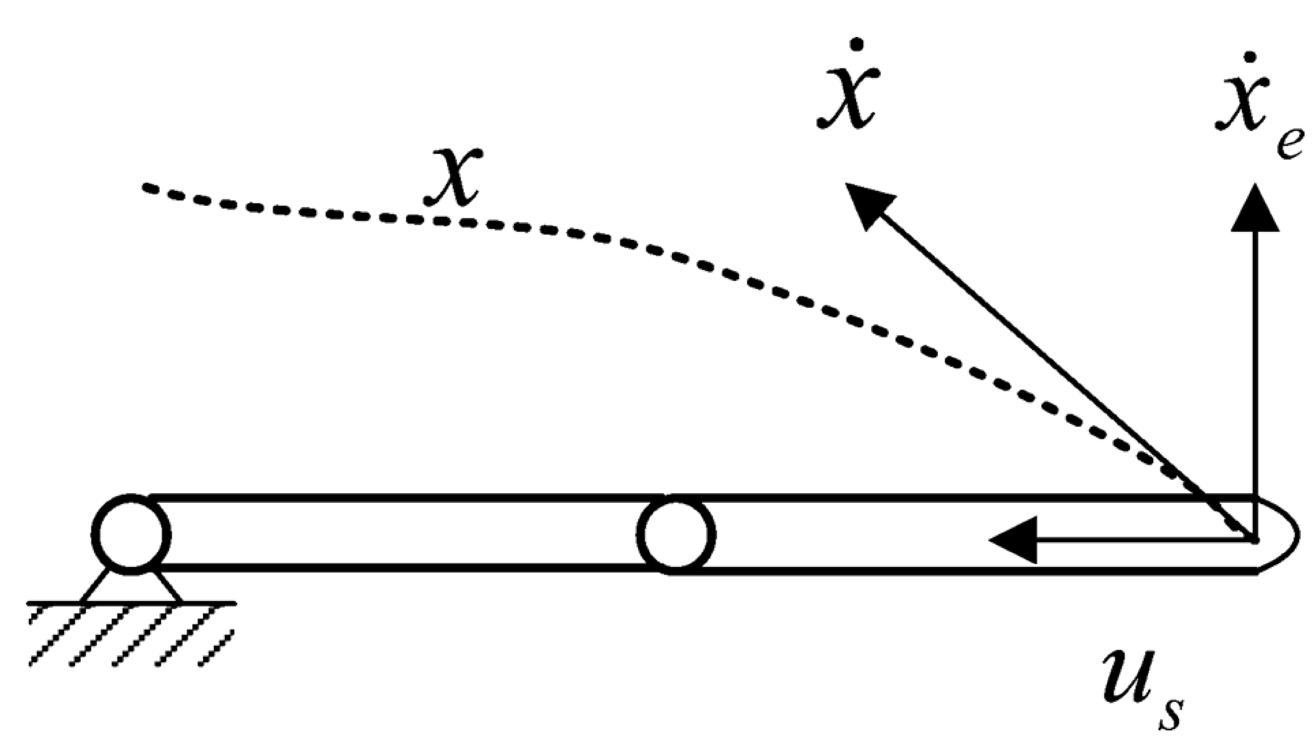
$$\dot{\hat{W}}_u = \gamma_w|e|,$$
$$\dot{\hat{B}} = \gamma_b|e|^2/2g_0^2,$$

yield asymptotic convergence of error to zero.
Then, we replace the adaptation laws as

$$\dot{\hat{W}}_u = \gamma_w[|e| - \varepsilon_w(e)(\hat{W}_u - W_{u0})],$$
$$\dot{\hat{B}} = \gamma_b[|e|^2/2g_0^2 - \varepsilon_b(e)(\hat{B} - B_0)],$$

where $\varepsilon_w(e) = \sigma_w|e|$ and $\varepsilon_b(e) = \sigma_b|e|$, $\sigma_w > 0$, $\sigma_b > 0$, W_{u0} and B_0 are the best guesses of the ideal parameters.

OTMM for Singularity Avoidance



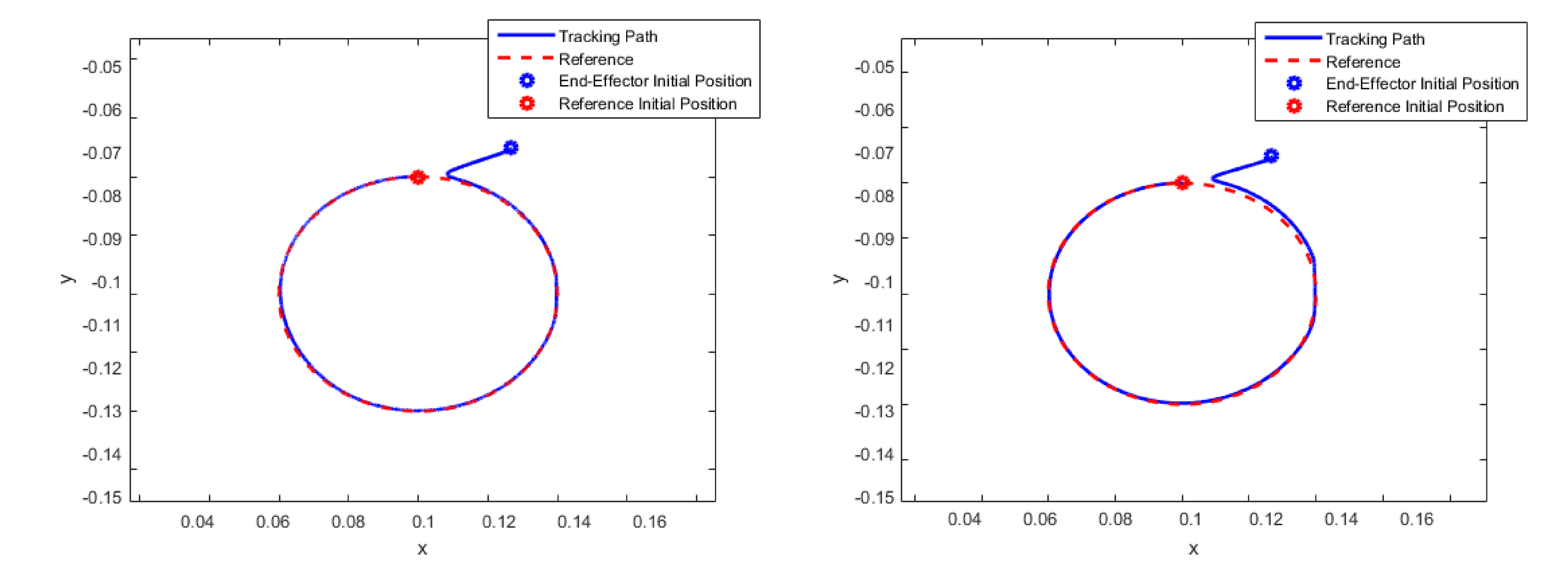
The OTMM equation is formed as

$$\dot{X}_m = \dot{X} - k \times \rho(\sigma_{min}) \times U_S \times U_S^T\dot{X}, k = \begin{cases} 0, \sigma_{min} > \sigma_s \\ 1, \sigma_{min} \leqslant \sigma_s. \end{cases}$$

where $\dot{X}_m$ is the modified task velocity, U_S is the singular direction vector, $\sigma_{min} \in \mathbb{R}$ is the minimum singular value of the matrix J, $\sigma_s \in \mathbb{R}$ is the low limit of the minimum singular value, $\rho(\sigma_{min})$ is a monotone function, where $\rho(\sigma_{min}) = 1$ when $\sigma_{min} = 0$ and $\rho(\sigma_{min}) = 0$ when $\sigma_{min} = \sigma_s$.

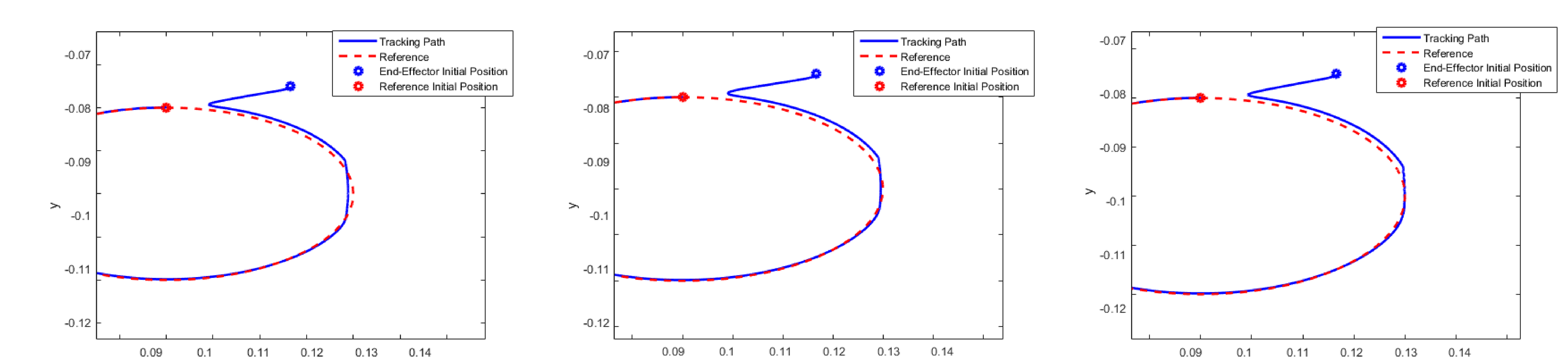
Simulation Results

- ϵ-Modification Method Implementation



(a)apply ϵ-modification (b)no ϵ-modification

- Singularity Avoidance by OTMM



(a)$\sigma_{min} = 0.1$ (b)$\sigma_{min} = 0.06$ (c)$\sigma_{min} = 0.02$

Conclusion

- ϵ-modification help keep the boundary estimator of adaptive controller robust with dynamic uncertainty;
- OTMM eliminates the need to differentiate the escapability of the singularities for HRR;

Real 9-DOF Arm Platform

(a) Home position 1 (b) Home position 2